Bellcomm

955 L'Enfant Plaza North, S.W.
Washington, D. C. 20024

B71 06066

date: June 30, 1971

to: Distribution

from: E. W. Radany

subject: Skylab Daylight Momentum Dump Requirements
Case 610

ABSTRACT

The Skylab cluster will generally perform a momentum dump maneuver once each orbit over an arc of central angle centered near orbit midnight. All, or most, of each dump maneuver typically will take place in darkness. At times during the mission when beta (the angle of the solar vector to the orbit plane) exceeds about 40 degrees however, a significant portion of each dump maneuver will be performed in daylight. In fact, there will be at least four days during any 236-day mission when every dump maneuver will take place entirely in sunlight, irrespective of the SL-1 launch date and time.

The momentum dump maneuvers commonly will involve angular excursions of about 12 degrees from the solar-inertial attitude. Consequently, some surfaces and/or components which are normally shadowed will be exposed to direct sunlight during those periods when totally or partially illuminated momentum dump maneuvers are required. Since it is known that daylight attitude excursions from the solar-inertial attitude (for example multiple Z-local vertical passes) can cause thermal problems on the various Skylab modules, investigation of the possible thermal implications of illuminated dump maneuvers may be warranted. This has been done in the case of the ATM and is being included in CSM thermal analyses. In order to help bound the problem, this memorandum presents data which shows when, and for what durations, the dump maneuvers will take place in sunlight for the currently baselined April 30, 12:30 EST launch of SL-1. In addition, the number of days of 100% illumination in a 236-day mission is parametrically determined for all possible Skylab launch dates and times. The parametric data show that a simple revision of launch conditions could not alleviate any thermal problems which might be engendered by illuminated dump maneuvers.

(NASA-CR-121356) SKYLAB DAYLIGHT MOMENTUM DUMP REQUIREMENTS (Bellcomm, Inc.) 14 p

N79-71708

Unclas
00/12 12098

FF No. 60

CR-121356
(NASA CR OR TMX OR AD NUMBER) (CATEGORY)

[redacted]

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MEMORANDUM FOR FILE

Introduction

It is presently planned that a Skylab momentum desaturation (dump) maneuver generally will be performed once each orbit. A dump maneuver presumably could be delayed for an orbit or two, however, if necessary to accommodate unusual experiment requirements. The dump maneuvers commonly will entail pitch and yaw angular rotations (around the ATM Y and Z axes, respectively) of ± ten degrees, and ± one degree rotatations in roll (around the ATM Z-axis); these maneuvers may occur simultaneously. Maneuvers of ± twenty degrees in pitch and yaw and ± five degrees in roll occasionally will also be required.

The negative yaw (ie., -z) axis is nominally pointed toward the sun when the cluster is in the solar inertial attitude. Consequently, during periods when the dump maneuvers are performed partially or entirely in daylight, separate yaw maneuvers will not expose any otherwise-shadowed surfaces or components. However, separate roll or pitch rotations, or combined rotations about any two or more axes will expose some particular additional area to direct sunlight.

Since it is known that substantial daylight attitude excursions from the solar-inertial attitude (for example, multiple z-local vertical passes) can cause thermal problems on the various Skylab modules, an investigation of the possible thermal implications of illuminated dump maneuvers may be warranted even though the attitude excursions involved are relatively small. (According to Mr. Howard Trucks, MSFC, such an investigation has already been done for the ATM and no thermal problems were uncovered. According to Mr. Art Frank, North American Rockwell, it is planned to include the effects of illuminated dump maneuvers in the CSM thermal analyses.) In order to help bound the problem, this memorandum investigates the requirements to perform momentum dumps in daylight for the presently baselined April 30, 12:30 EST SL-1 launch condition and associated mission sequence; reference 1. The number of days during a 236-day mission requiring fully illuminated dump maneuvers is also determined for parametric SL-1 launch conditions.

Discussion

Skylab momentum dump maneuvers will be performed over an arc of central angle centered near orbit midnight. The central angle required to complete a dump maneuver, and the displacement of the dump arc with respect to orbit midnight, are functions of beta (the angle of the solar vector to the orbit plane) and of the spacecraft mass properties. The mass properties at the start of each mission phase (Table A-1) were assumed constant for the duration of that phase for the purpose of this study. The central angle of the orbit which is in darkness likewise is a function of beta, and of the orbit altitude. As a consequence of these relationships (which are formulated in the Appendix), portions of dump maneuvers will at times occur in daylight, even though the central angle of the orbit which is in darkness exceeds the central angle required to complete the dump maneuver. Furthermore, a 235 nautical mile altitude circular orbit will be completely illuminated when beta exceeds 69.4 degrees, and the entire dump maneuver would necessarily have to be performed in daylight. The time history of beta for the baseline launch condition is presented in Figure 1.

A minimum nominal dump arc of 108° is currently planned. The minimum dump arc will be increased to 126° during the mission if required by contingencies (2 CMG operation, excessive venting or leakage torques, etc.); Reference 2. The histories of the duration of orbit night and of the times required for dump maneuvers are presented in Figures 2 and 3 for the two values of minimum dump arc. Orbit night is denoted by positive-slope cross-hatching in these figures; sunrise and sunset are symmetrical around orbit midnight, of course. The duration of the dump maneuvers is indicated by the regions having negative slope cross-hatching. Momentum dump maneuvers thus will be performed (entirely or partially) in daylight in those regions where only negative-slope cross-hatching is present.

One isolated 4-1/2 day interval of full orbit illumination occurs around mission day 40 for either value of the minimum dump arc. (This is strictly a consequence of the magnitude of beta). On a once-per-orbit basis this implies that approximately seventy consecutive, fully illuminated dump maneuvers will have to be performed during this period. The maximum duration of a fully illuminated dump maneuver with the 108° minimum dump arc is about 28 minutes. Three other intervals during which partially illuminated dump maneuvers will be required occur with the 108° minimum dump arc; these intervals are centered around mission days 100, 161, and 192. On mission day 100 the dump maneuver starts about 8-1/2 minutes before sunset and ends about three minutes after sunrise. On mission day 161 the dump maneuver will start about 1-1/2 minutes before sunset, but will end before sunrise. On mission day 192 the dump maneuver will begin about nine minutes before sunset and will end about 4-1/2 minutes after sunrise. For the 108° minimum dump arc, the dump maneuver begins at sunset over the major portion of the mission, simply as a result of the definitions of the dump parameters; see Appendix.

The maximum duration of a fully illuminated dump maneuver (occurring on mission day 40) with the 126° minimum dump arc is about 32-1/2 minutes. Dump maneuvers will begin before sunset during the entirety of both unmanned phases, as well as for the majority (all except about ten days) of the SL-3 mission. Two intervals during which substantial portions of the dump maneuvers are performed in daylight are again centered on mission days 100 and 192. On mission day 100, the dump maneuver will begin about 11 minutes before sunset and end about six minutes after sunrise; or a total of about 17 minutes of illumination per maneuver. On day 192 the dump maneuvers will be illuminated for a total of about 19 minutes.

Figure 4 is presented as a generic extension of Figures 2 and 3 which apply specifically to the baseline mission. In generating Figure 4, the launch conditions were incremented at three-hour intervals on each launch date, the launch date was incremented at five-day intervals over the year, and the number of days of full orbit illumination occurring in a 236-day mission were tabulated. The slope of the cross-hatching in the various regions of Figure 4 reflects the associated number of days of full illumination: i.e. shallowest slope -- least number of days of full illumination, etc. Figure 4 shows that fully illuminated dump maneuvers will be required on at least four days of any 236-day Skylab mission, irrespective of the launch conditions selected for SL-1.

Summary and Conclusions

As noted in the memorandum, a period of about 4-1/2 days of full orbit illumination occurs during the first unmanned mission phase for the currently baselined launch conditions. About seventy consecutive dump maneuvers, each about a half hour in duration, will have to be performed in full daylight during this period. While the excursions from the solar-inertial attitude during the momentum dump maneuvers are small compared to Z-local vertical maneuvers, the long periods over which the dump maneuvers have to be performed in full daylight might cause a thermal problem on one or more of the Skylab modules. Accordingly, investigations of the adequacy of module thermal design should take account of this situation. Should the performance of fully illuminated dump maneuvers in fact prove to be thermally troublesome, a simple revision of the launch conditions alone could not alleviate the problem.

E. W. Radany

1025-EWR-li

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Attachments
Appendix
Figures

REFERENCES

1. Trip Report - Thirty-Fourth Skylab Flight Operations Plan (FOP) Meeting, MSC, April 17, 1971, D. J. Belz, Bellcomm Memorandum for File B71 04021, April 14, 1971.

2. Skylab Typical Momentum Desaturation Maneuvers, W. Levidow, Bellcomm Memorandum for File B71 06001, June 1, 1971.

3. Solar Pointing Variations in Earth Orbit and the Impact on Mission Design, B. D. Elrod, Bellcomm Technical Report TR-70-1022-1 (page 38), February 11, 1970.

4. Skylab A Orbital Mass Properties Data, MSFC S&E-ASTN-SAE-71-8, February 1, 1971.

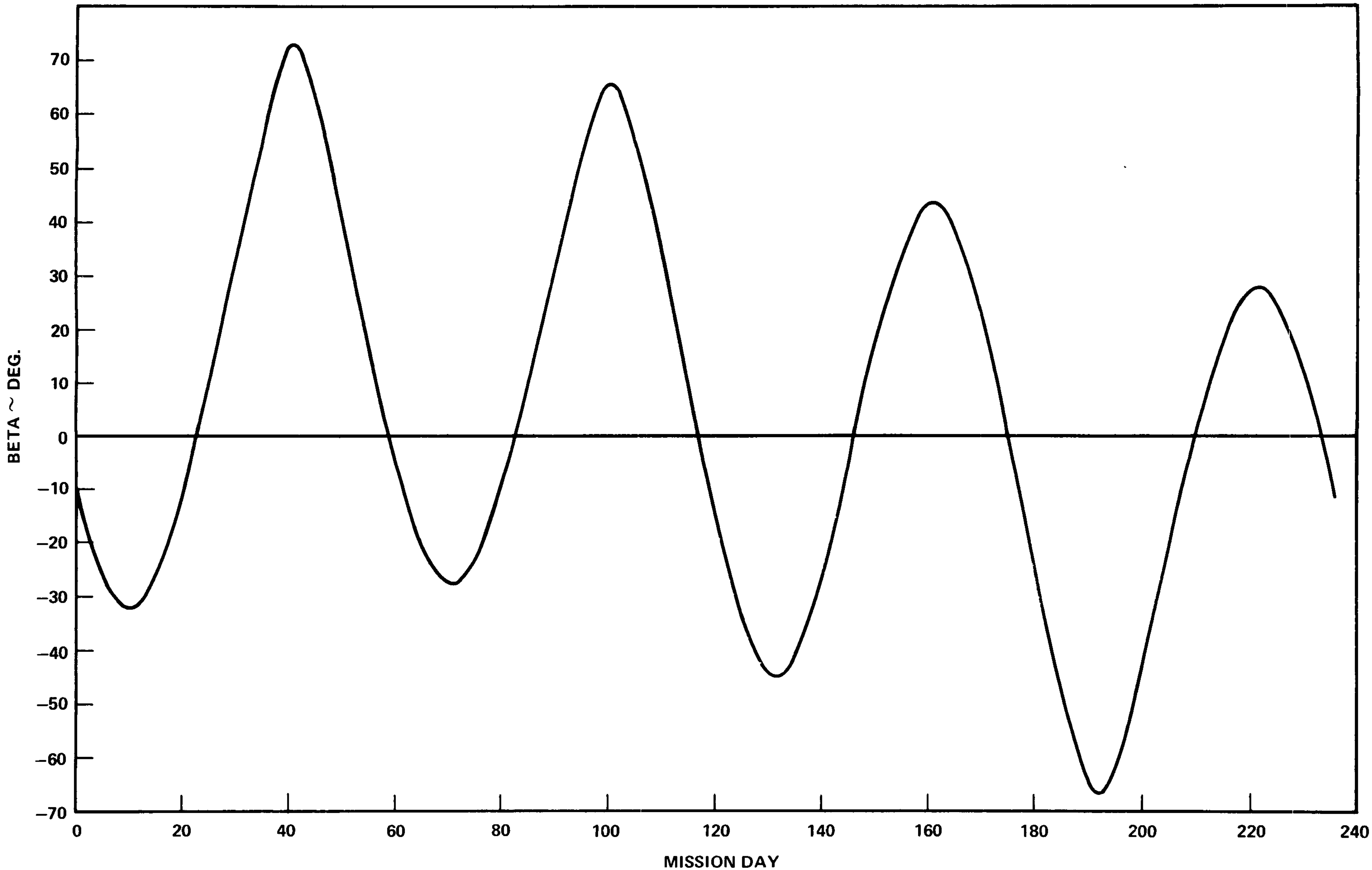


FIGURE 1 - TIME HISTORY OF BETA, ANGLE OF SOLAR VECTOR TO ORBIT PLANE
APRIL 30, 1230 EST SL-1 LAUNCH

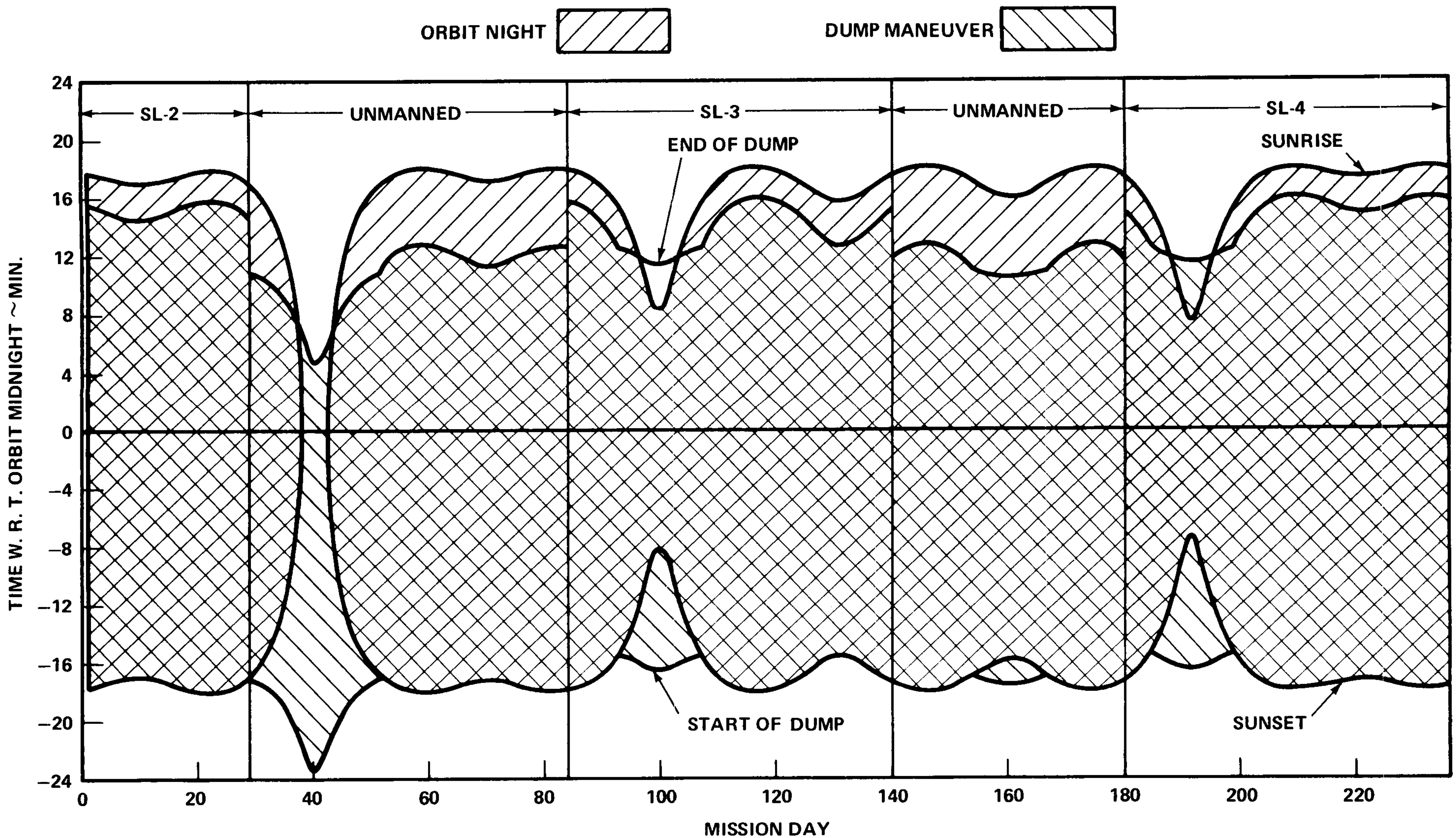


FIGURE 2 - HISTORIES OF ORBIT NIGHT AND TIME REQUIRED FOR DUMP MANEUVERS
APRIL 30, 1230 EST SL-1 LAUNCH; MINIMUM TOTAL DUMP ARC = 108°

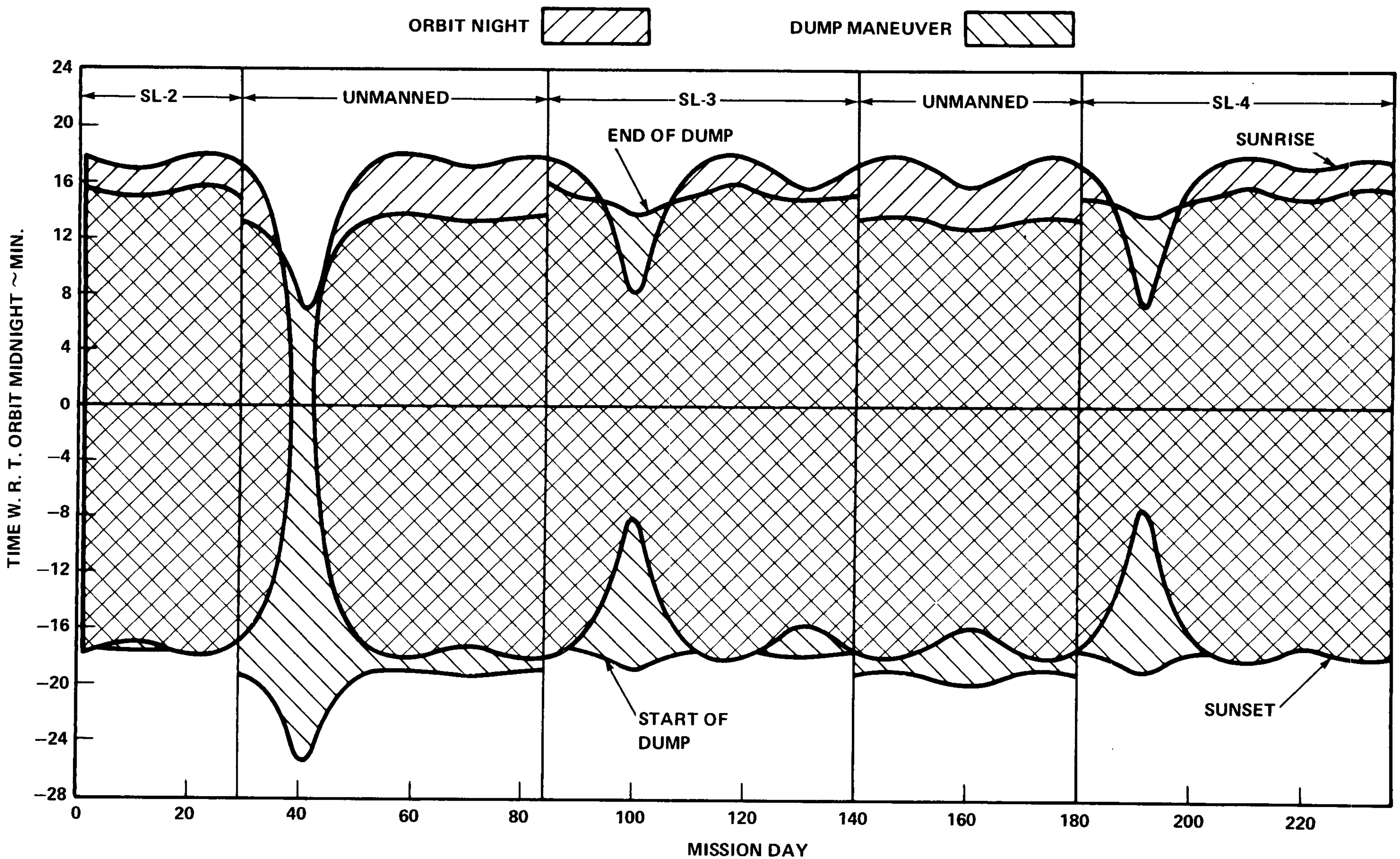


FIGURE 3 - HISTORIES OF ORBIT NIGHT AND TIME REQUIRED FOR DUMP MANEUVERS
APRIL 30, 1230 EST SL-1 LAUNCH; MINIMUM TOTAL DUMP ARC = 126°

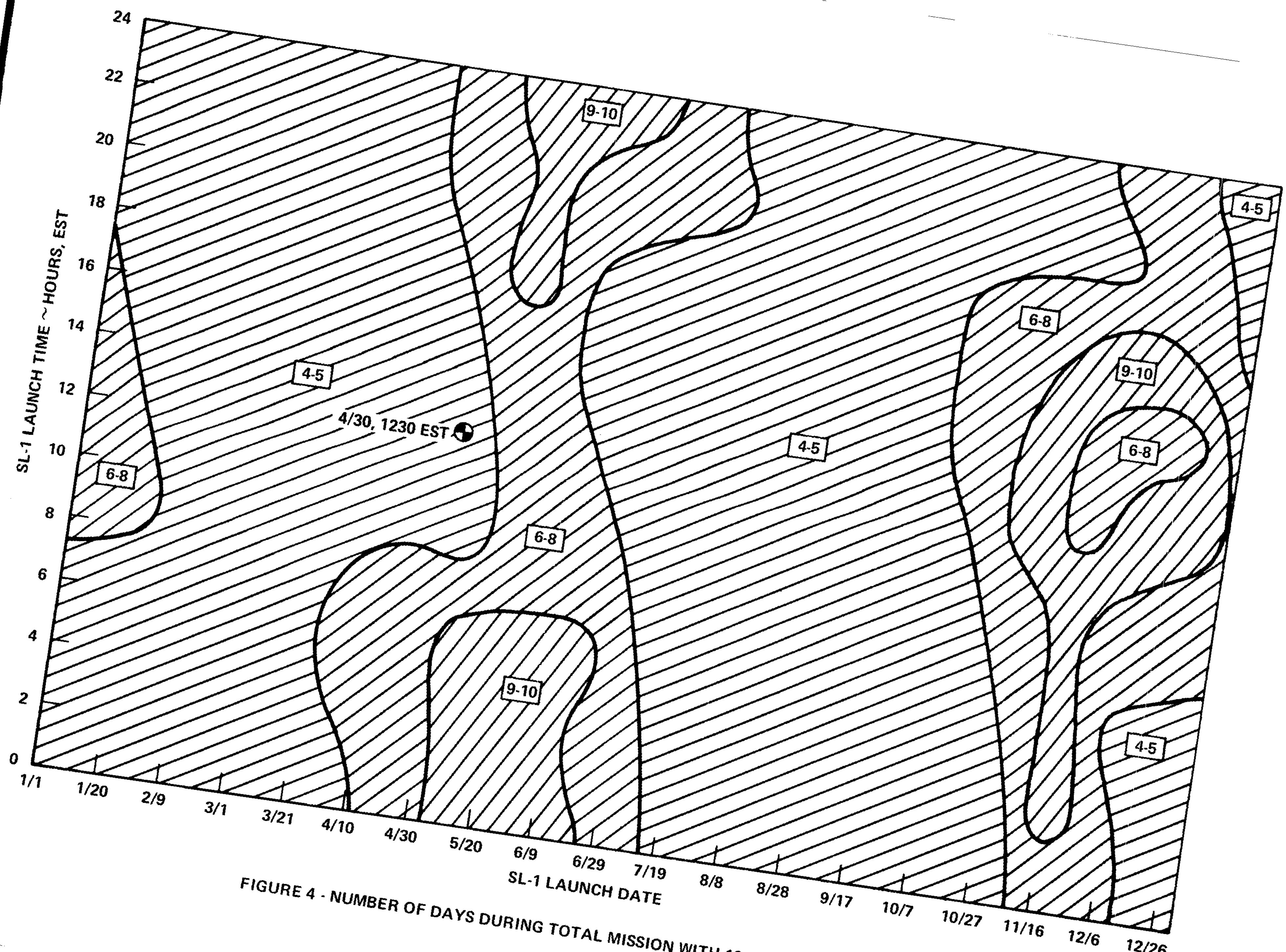


FIGURE 4 - NUMBER OF DAYS DURING TOTAL MISSION WITH 100% ILLUMINATION

APPENDIX

The following equations are the basis for the data presented in the memorandum. The associated geometry is illustrated in Figure A-1.

The central half-angle of the shadowed portion of the orbit (ρ_s) is related to the angle of the solar vector to the orbit plane (β) by the expression (Reference 3),

$$\cos \rho_s = \frac{\cos \left[\sin^{-1}\left(\frac{Re}{Re + h}\right)\right]}{\cos \beta},$$

where Re = radius of the earth, and

h = orbit altitude.

A 235 nautical mile circular orbit will become completely illuminated when the magnitude of beta exceeds 69.4°, thus precluding the performance of momentum dumps entirely in the dark.

The center of the dump arc will be biased with respect to orbit midnight by the angle η_{TM}, measured as positive in the direction of motion, where

$$\eta_{TM} = -\tan^{-1}\left\{\frac{S\eta_x\,(a_{11}\,S\nu_z + a_{12}\,C\nu_z) + a_{13}\,C\eta_x}{a_{11}\,C\nu_z - a_{12}\,S\nu_z}\right\}$$

The functions "S" and "C" in the preceding equation denote the sine and cosine, respectively. This definition of η_{TM} locates the center of the dump arc at the point on the orbit where the x principal moment of inertia axis is perpendicular to the radius vector, a requirement imposed by the symmetry of the control equations. In the foregoing expression,

$$\eta_x = -\beta,$$

$$\nu_z = \sin^{-1}\left[\frac{a_{13}\tan \eta_x}{\sqrt{a_{11}^2 + a_{12}^2}}\right] - \tan^{-1}\left(\frac{a_{12}}{a_{11}}\right), \text{ and}$$

a_{1j} = the direction cosines between the X principal moment of inertia axis and the Workshop vehicle coordinate system axes.

Values of the a_{1j}, assumed constant during each of the five phases of the mission, are presented in Table A-1.

The central half-angle required to perform a momentum dump maneuver (ρ_D) is given by

$$\rho_D = \rho_S - |\eta_{TM}| ,$$

It is currently planned that ρ_D will normally be clipped at a minimum of 54°. This will be increased to 63° during the mission if required by contingencies. The foregoing expressions for η_{TM}, ν_z, and ρ_D were obtained from Reference 2.

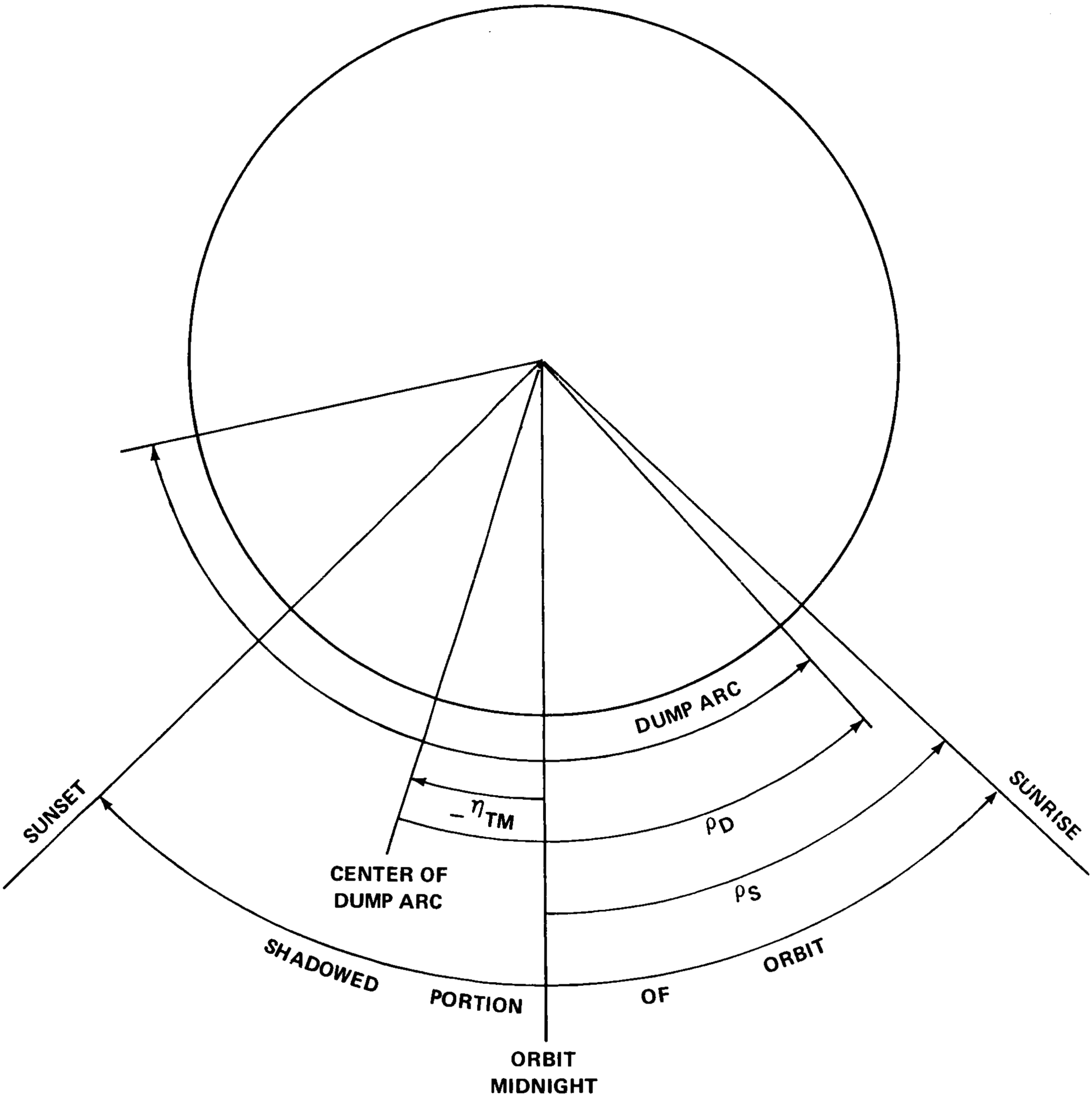
As is illustrated in Figure A-1, the displacement of the center of the dump arc away from orbit midnight by the angle η_{TM} can, at times, cause a portion of the dump to occur in daylight, even though the central angle of the shadowed portion of the orbit exceeds the central angle required for the dump maneuver.

Table A-1

TRANSFORMATION COSINES*

Mission Phase	a_{11}	a_{12}	a_{13}
SL-2	.997367621E-00	.293576671E-02	.724466445E-01
Unmanned	.984687329E-00	.874086658E-02	.174107253E-00
SL-3	.997516752E-00	.237735361E-02	.703870804E-01
Unmanned	.985041143E-00	.607109629E-02	.172209829E-00
SL-4	.997544528E-00	.137083796E-03	.700279476E-01

*Reference 4.



VIEW IN DIRECTION OF NEGATIVE ORBIT MOMENTUM VECTOR

FIGURE A-1 - MOMENTUM DUMP GEOMETRY